CHARACTERIZATION AND SETTLEMENT ANALYSIS OF MUNICIPAL SOLID WASTE

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ABSTRACT

Waste management is an integral part of the society and its proper management falls under the purview of urban local bodies (ULB) or municipalities of different cities in developing country. Solid waste generation and composition and thereby selected treatment measures varies within countries and are influenced by prevailing waste management systems, economic conditions, rate of urbanization, habits and life style of the people. Further, due to the increased urbanization, migration from village to cities has rapidly increased leading to additional increase in generation of the MSW. Therefore, it has become important to take into consideration all these factors and ascertain composition and quantity of waste before selecting and implementing waste management strategies for a particular area. Waste treatment option suitable for a particular area may not be necessarily effective for another area. Therefore, selection of treatment options for particular locality should be made keeping in view various factors like waste generation trends, variation in waste composition and population growth rate.

Municipal solid waste management is an important function of urban local body (ULB) of any city or town in India. Therefore, considering the environmental impact and health issues of dumping waste, current study emphases on the assessment of existing practices of waste management in study area and characterizing the waste generated and evaluating the impact of open dumping on soil and analyzing the settlement. The 'wasteaware' benchmark indicators were used for determining the present waste management system of MSW in Una and preventive measures were suggested. The wasteaware benchmark indicators showed very poor performance in environmentally controlled waste treatment, disposal method of waste and the *3R* methodology.

For the implementation of efficient management practices in the study area, categorization and characterization of MSW is an important factor in providing cost effective and environmentally compatible management system. In this context, characterization and energy generation potential of municipal solid waste determined over three seasons (summer, monsoon and winter) to eliminate any seasonal biasness for Una town, a Tier-IV city of Himachal Pradesh. The characterization study revealed that waste generated in the study location is rich in organic content (56%) followed by plastic (10.3%) and inert materials (10.5%). The chemical characterization revealed that the average C/N ratio of waste is 22.72 which are indicative that

the MSW generated is suitable for treatment of organics including composting and energy generation. The average calorific value of 2263 kcal/kg showed that the energy content in MSW is high due to presence of food waste, paper, plastic which makes it suitable for installation of energy recovery and waste to energy units.

The effect of degradation on geotechnical characteristics of waste was also assessed in present study. The particles of waste get finer with decomposition and results in variation in properties by converting organic component to inorganic. The determination of effect of degradation for landfill stability is function of unit weight, moisture content, organic content, compressibility, shear strength. The moisture content was observed to be 49.5±1.05% for fresh and 39.8 to 51.6% for degraded (old) waste respectively. The specific gravity and unit weight of waste were observed to be increased with degradation of waste. The maximum dry density (MDD) was observed to be 4.28 kN/m^2 for fresh waste at the optimum moisture content (OMC) of 78.1% and 4.47 kN/m^3 for six months old waste and 6.25 kN/m^3 for the degraded waste of 5-6 years at 80.2, 85.4% of OMC respectively. The hydraulic conductivity of landfilled waste is less than fresh waste attributed to increased finer particles in degraded waste. The shear strength of MSW was observed to be increased with the degradation of MSW. The cohesion (c) and angle of internal friction (φ) varied between 31.2 kPa (fresh) to 38 kPa (degraded) and 14° to 22° with the increase in waste degradation. The compression ratio of fresh waste was within the ranges of 0.19-0.29 and for degraded MSW it varied between 0.12-0.17 respectively. A weak correlation between degree of decomposition and geotechnical properties of waste exist due to heterogenous nature of MSW. The degradation of waste results in the differential settlements and thus it is necessary to assess the stability of landfill.

The stress behavior of MSW was evaluated by large scale direct shear test. The study investigated the effects of waste composition, confining stress, unit weight, and loading rate on the stress–displacement response and shear strength of MSW. The observed results showed that the confining stress and loading rate are important factors. The effect of degradation of MSW with depth on shear strength characteristics observed an increase in the φ cohesion of waste. Based on large-scale direct shear tests, the shear strength of MSW is best characterized by cohesion 32 kPa, friction angle 20̊.

The effect of disposal of MSW on geotechnical properties was evaluated in this study. It was observed that the degradation of waste causing percolation of leachate into soil affecting the

strength and stability of soil. The geochemical analysis was carried out by Energy Dispersive X- Ray Spectroscopy (EDX) and Scanning Electron Microscopy (SEM). The elemental analysis of soil exhibited presence of high oxygen and silica content in uncontaminated soil. The analysis depicted that specific gravity, maximum dry density (MDD), permeability and California bearing ratio (CBR) showed decreasing trend variation for polluted soil. The results showed that MDD reduces from 17.18 kN/m³ to 16.5 kN/m³ and OMC increases from 15.8% to 17.5% for the contaminated soil compared to uncontaminated soil for which MDD is 17.1kN/m³. It was observed that cohesion for contaminated soil was found to be increased thereby increasing the shear strength of soil. The CBR value of dump soil as compared with the natural soil decreased by 12% -17% and 20-25% for un-soaked and soaked conditions. The effect of temperature, pH and moisture content hold a significant position for assessing the settlement. The settlement of soil due to biodegradation of MSW is estimated using empirical mathematical model for dump site depending upon pH, moisture content and temperature.

The study also evaluated the behavior of MSW under the anaerobic condition to analyze the settlement of MSW. The settlement of MSW is due to high compressibility under influence of biodegradation of organic content and overburden load. The observed results showed that the waste of the study area is rich in organic content and thus have higher rate of degradation. The settlement of waste observed under the constant loading was higher during the initial stage. The immediate settlement of 29.9% was determined and it was observed that the primary settlement of waste was completed after 48 hours of application of load. The secondary settlement of 5.96% was achieved at 202 days of degradation of waste and it continues till the decomposition of waste occurs completely.

Keywords: Municipal Solid Waste Management, Wasteaware Benchmark Indicator, Degradation, Shear Strength, Settlement.

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1. INTRODUCTION

1.1 Solid Waste

The waste within household, communities, market and public service actions is an inevitable by-product of the human activities. These activities are domestic, agricultural, commercial, industrial and satisfying the growing needs of habitats resulting in generation of waste. Due to growing industrialization, urbanization and prospering economy in India, the generation of MSW has increased to large extent which results in difficulties for its management to people and urban local bodies (ULB). The mismanagement of solid waste and unscientific disposal may lead to health hazards and environmental problems. Thus, the generated solid waste if managed properly can be reused as a source for the energy generation and fuel recovery. The proper management of waste needs the cooperation and collaboration for the efficient delivery and comprises the aspects for generation of waste, collection, transportation, recycling, treatment and final disposal.

1.2 Waste Generation and management in India

Being the second most populated country, India is one of the fastest growing economy in the world. The continuously rising population of nation has imposed a massive burden on economy, resources and the health services. In developing countries like India, the waste generated has a high fraction of biodegradable matter about 35-60% with higher moisture content and density because of food and cultural habits of people (Khajuria et al., 2010, Hoornweg et al., 2013, Joshi and Ahmed). In India, the overall MSW generation is projected to be about 52 million tonnes per year (CPCB Report) out of which 23% is processed and taken to the landfill for final disposal. The growth rate of population of the country is 17.6% (Census 2011) with per person waste generation rate of 0.2-0.87kg/day having increasing rate of 1-3% per year (CPCB 2016, Rana et al. 2015).

As per the Report of World Bank (2012), waste generation in India is estimated to be 1.2-1.42 kg per person per day by next 15 years (World Bank Asia 2014,2016,2018). The urban areas in India contributes majorly in the waste generation of more than 1,00,000 MT per day (CPHEEO2016a, 2016b, Urban Waste management 2015). The large metropolitan cities like Mumbai generates waste about11000 MT/day, Delhi about 8500 MT/day, Bangalore about 5000 MT/day and other large cities Chennai, Ahmedabad generates about 4000-5000 MT/day of waste (CPCB 2017, Urban SWM 2015). The increase in waste generation in large Indian

cities is shown in *Figure 1.1.1* (CPCB 2015).

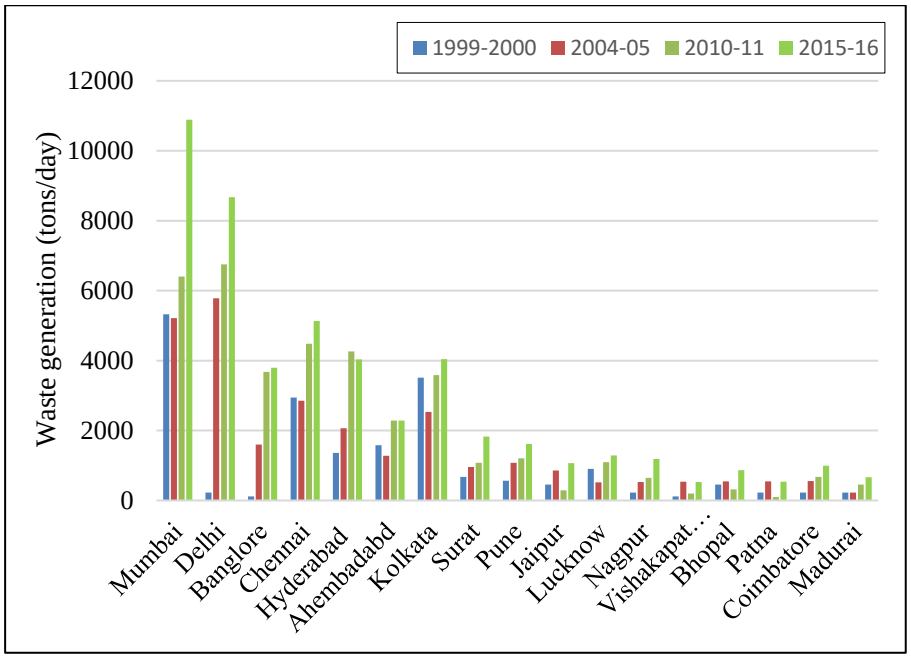

Figure 1.1.1: Waste Generation in Indian Urban cities.

1.3 Environmental Impacts

In India major portion of the MSW is discarded in open dumping sites without giving any prior treatment. Dumping of MSW in open sites will have significant impact on the environment and also effect health of humans and other living beings in the vicinity area (Gajski et al, 2012; Faccio et al 2011). Major fraction of the MSW includes organic components therefore soon after dumping waste will undergo changes which lead to generation of various emissions in the form of leachate and gases. The biodegradable fragment present in MSW undertakes various biogeochemical and hydrological reactions in the presence of moisture to produce a liquid generally termed as 'leachate'. Many studies (Thakur et al, 2015; Talalaj et al, 2016; Yadav et al, 2014; Ghosh et al, 2014a; 2014b) reported that leachate contains numerous organic and inorganic compounds like humic acids, salts, ammonical nitrogen and heavy metals. Anaerobic degradation of MSW leads to generation of gases like methane (CH_4) and carbon dioxide (CO_2). Landfill gases are directly emitted to the atmosphere from the open dump sites and are considered to be major contributor of global warming due to emission of methane a greenhouse gas (GHG) which has 21 times more global warming potential as compared to carbon dioxide. A number of studies (Kaur et al, 2016; Giusti, 2009; Guerrero et al, 2015; Gupta and Rajamani, 2015; Rana et al., 2014; 2016) have also reported that a higher percentage of workers involved in handling of refuse or the individuals living near the dumping sites are suffering from various

types of health problems like gastrointestinal parasites, worms and other related organisms.

MSW disposed in open land and low laying areas without any preventive measures becomes a cause for soil and ground water pollution (Nayak et al., Amadi et al., 2012). The heterogeneity of MSW and its complex characteristics affects the soil texture, color, agricultural and engineering properties. The leachate generated due to degradation of MSW contains toxic chemicals and organic, inorganic compounds, heavy metals (Cd, Pb, Cr, Zn, As etc.), migrates into soil and thereby polluting the soil and ground water. Soil pollution due to dumping of MSW, alter the properties of soil and also having impact on soil organisms and vegetation growth in soil (Sulaiman et al., 2016).

The composition and heterogeneous nature of MSW affects the void ratio, water content, unit weight, shear strength and compressibility and are important parameter for analyzing landfill performance (Machado et al. 2010). However, the composition and characteristics of waste varies with moisture content for developing and developed (Kumar et al. 2009, Joshi and Ahmed 2016)**.** Also, the degradation of organic matter of MSW occurs due to micro-organisms present and moisture content which influences the physical stability of structure. This process occurs in different phases of aerobic, transition, acidogenesis, acetogenesis and methanogenesis and thereby increasing the rate of degradation. Waste degradation changes properties of municipal solid waste and these changes are used for assessing the geotechnical stability and failures like cracking, settlement, slope stability of landfill (Reddy et al. 2015).

1.4 Waste Management Policies in India

Various rules and policies have been framed in India to tackle the problems of waste with an aim to reduce the risks to human health and environment. MSW (Management and Handling) Rules, 2016 lay down the procedures and guidelines for segregation, collection, storage, transportation, processing and disposal of MSW throughout India. The rules are applicable to all the municipalities and are framed in order to make citizens well aware of their responsibilities so that they can practice guidelines for an effective management of MSW.

1.5 Review of Literature

For defining the objectives and scope in the proposed research area a detailed literature survey is carried out both in terms of theory and experimentation. A brief literature review conducted helps in providing knowledge for further innovative, safe and efficient design for MSW management.

Van de klundert 1999 depicted for handling the waste, ISWM was introduced in 1995, that includes activities like generation, collection, transport, separation, recycling and disposal for efficiency of system. To attain the sustainable solid waste management, improvement in policies, rules and regulations, legal framework is obligatory. Therefore, the Municipal Solid Waste Management Rules (2000) for handling and managing the waste has made it mandatory for administration to take all responsibility of waste except generation.

WHO, 1999, conducted a survey stating that generation, quantity of MSW varied for countries, place of living, state, region, areas. However, the growth in population and urbanization has added volume to waste generation and thus required recovery and reclamation services in areas. The developing countries facing problems associated with waste management system are critical than developed countries. The reduction in quality of services provision for waste management was due to lack of financial resources available.

Generation of waste showed increasing trend with population and urbanization (Mor 2006). The study (Sharholy 2008) showed that urban India generates about 48 million tonnes of MSW and this may rise up to 250 million tonnes by 2050. The processes followed are being done in haphazard manner which reduces the efficiency and therefore, management, handling of waste has become the responsibility of municipalities. Thus, for the sustainable waste management segregation, collection, storage and treatment of waste are the condemnatory elements which affects environment (Giusti 2009). However, the effective waste management is leading matter of concern in developing countries like India.

The study (Shekdar 2009) analyzed and compared the characteristics of different seasons and socio-economic groups indicating that lowest income group produced least amount of waste. The study also stated that for waste characterization for different socio-economic groups and seasons concluded that the waste generated is less during the winter and low-income group generates least amount of waste. Generally, the trend of throw away culture and disposing waste in landfill or open dumps is being followed throughout the world. Knowing the fact that for sustainable development limited resources are available therefore economic opportunities from waste needs to be utilized.

The study conducted by Nandan et al. (Nandan 2017) revealed that major class I cities (population > 1 lakh) in India generates about 32,460 TPD of waste which includes major Indian cities like Delhi, Mumbai, Chennai, Ahmedabad, Kolkata, Hyderabad and Bangalore

(NEERI 2015). It was estimated that population of country would be 1823 million by 2051 and MSW generated would be 300 million tons annually (Joshi and Ahmed, Energy Research Institute).

The physical and chemical characteristics analyzed by Sethi et al. **(2013**) observed the higher fraction of biodegradable and inert content in municipal waste. The seasonal variation was observed mainly in compostable matter is during summer and winter seasons. The biodegradable matter in waste accounts about 32.5 ±6.2%, paper 3.65±2.28, plastic 6.5±1.98, glass 0.2±0.19 and 33.12±5.4 for inert fraction. The volatile fraction in waste was observed to be 20.4±4.45%, ash content 42±7.05%, fixed carbon 7.5±4.34 and calorific value 4270±160.2 kJ/kg. The carbon present is 28.2±3.28%, hydrogen 3.77±2.25%, Sulphur 0.63±0.65% in waste.

Katiyar et al., 2013 conducted a study on characterization of MSW in Bhopal, India. The study observed that the waste management process in the city is inadequate and inappropriate due to poorly designed bins, torn out collection vehicles, lack of man power including poor waste collection and treatment facilities, processing and disposal facilities. The waste collected from the city was observed to have higher moisture content and low calorific value. Thus the treatment facility adopted is aerobic composting and high plastic waste generation promotes the waste recovery goals.

The study conducted by **Reddy et al., 2015,** observed the behavior of MSW under recirculation of leachate. The leachate recirculation in MSW results in increased biogas generation and accelerated the biodegradation. The organic content of MSW was decreased from 84 to 58% and unit weight increased from 7.12 to 10.79 kN/m^3 from fresh to highly degraded waste respectively. The permeability of waste reduced from 10^{-2} to 10^{-4} cm/sec from fresh to degraded waste. The primary compression ratio was observed to follow the increasing trend with degradation and varies from 0.24 to 0.32. The cohesion of waste decreases with vertical stress and angle of internal friction decreases from 30˚ to 12˚ for initial stage of degradation to most degraded waste.

The study conducted by **Rana et al., 2017** also observed that the waste in tricity region is having higher fraction of organic content followed by inert fraction. The biodegradable fraction found in waste from Chandigarh is about 52%, Mohali 46.7% and for Panchkula 42.6% and inorganic fraction was found to be 17.4%, 15.1 and 15.7% for Chandigarh, Mohali and

Panchkula respectively. The moisture content in waste is 50% for Chandigarh, 46% Mohali and for Panchkula 40%. The average calorific value of waste was found to be 1929 kcal/kg for Chandigarh, 1801kcal/kg Mohali and 1542 kcal/kg for Panchkula. The carbon content in waste varied from 38.18%, 33.8%, 31.9% and oxygen 11.41%, 10.2%, 11.1%, hydrogen 4.42%, 4.2%, 4.2% and nitrogen about 1.35%, 1.53%, 1.1% for Chandigarh, Mohali and Panchkula respectively. The elemental composition observed thus help in determining type and treatment facilities for waste component.

Kaza S. 2018 reported that municipalities in low income countries spent 20% of their budget on waste management despite of that 90% of waste is being openly dumped or burned.The solid waste management system in middle income and high-income countries in world accounts for more than 10% and about 4%of budget for waste management. It was estimated that the waste generation across the world was about 2.01 billion tonnes annually and about 33% of waste was in an environmentally safe manner.

1.6 Research Objectives

The objectives for the present research work comprise:

1) To evaluate the existing municipal solid waste (MSW) management practices in Una Town, India.
2) To determine the physical and chemical characteristics of municipal solid waste in Una town.
3) To assess the effect of degradation on geotechnical properties of municipal solid waste.
4) To study the impact of degradation on stress-strain behavior of MSW.
5) To evaluate of effect of MSW dumping on geotechnical properties of soil and analysis biodegradation settlement of soil.
6) To determine the settlement of municipal solid waste under anaerobic digestion conditions.

1.7 Organization of Thesis

The first chapter is essentially an Introduction to the study conducted which gives an overview on solid waste and status of waste management in India including generation, collection, storage, transportation and final disposal of waste. Additionally, chapter also highlights the effects on environment including water, soil and air pollution and human health because of non-engineered landfill sites and open dumping of waste. Further, the initiatives and steps taken

for waste management and handling by government and responsibility of municipalities and ULB's are also discussed.

The second chapter deals with review of available literature related to management of MSW and consequence of dumping waste openly or unscientifically on environment in global and Indian context. The studies showing the geotechnical behavior of MSW, effect of aging on properties of MSW and its impact on soil and surrounding environment is discussed in this chapter. The research carried out earlier and facts and gaps in the context of present research work are discussed in this chapter.

The third chapter discussed the existing MSW management practices carried out in study location Una, town, Himachal Pradesh. The analysis of current management practices in study area is done using Integrated Solid Waste Management (ISWM) benchmark indicators. This method is also called as "*wasteaware"* benchmark indicator is used along with the matrix method for quantification and understanding system analysis approach for improving, analyzing and understanding the efficiency of SWM services. The suggestions and recommendation have been presented in this chapter for improvement of waste management practices in the town.

Fourth chapter present the physical and chemical characteristics of waste for different seasons (summer, monsoon, winter) for analyzing the energy potential (calorific value) of MSW to manage waste generated for sustainable development. The mathematical models were used to assess the energy generation potential in terms of calorific value of waste. Different waste to Energy (WTE) techniques for utilization of energy value based on characterization results are also discussed in this chapter.

The fifth chapter presents the analysis of geotechnical properties of waste to determine the strength, compression characteristics etc. which can further be utilized for evaluation of settlement of landfill.

The sixth chapter deals with the analysis of stress strain behavior with aging/degradation of MSW. The effect on shear strength of MSW due to degradation is an important factor in term of consideration of landfill slide failure, settlement of landfill.

The seventh chapter presents the effect of MSW on geotechnical properties of soil with in the periphery of dump site. The chapter discussed the variation in geotechnical properties of soil in comparison with natural soil to assess the level of pollution due to direct disposal of MSW on the land. The scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDX) techniques has been used to analyze the element configuration and morphology of dump soil and natural soil as well. Additionally, the effect of dumping on biodegradation settlement of soil has been analyzed using mathematical models for reducing the possibility of damage to engineered structure provided over the MSW landfill.

Chapter eight deals with the evaluation of settlement of MSW under the anaerobic digestion condition being a vital element for designing of landfill. It includes the biogas determination (CO_2, CH_4), leachate quality, temperature variation and rate of biodegradability of MSW under the simulated laboratory conditions. In this context, the settlement of MSW is determined under the different loading conditions, with leachate recirculation to increase the rate of biodegradation.

Chapter nine discusses the summary and conclusions derived from the study and also some recommendations for improving waste management practices in Una town are given mentioning the future scope of the research work.

2. METHDOLOGY

2.1 Prevailing Waste Management Practices and Msw Management Analysis in Una

2.1.1 Introduction

The current study emphasizes the existing waste management practices carried out in the Una town of Himachal Pradesh (Figure 2.1). The efficiency of prevailing practices for functioning of existing MSW management system in town, were analyzed using the "*wasteaware*" method which was further quantified using the "*matrix method* "and the results obtained compared with other similar study locations within the state of HP. Additionally, for improvement of current waste management practices in the study region, some appropriate remedial measures have been proposed.

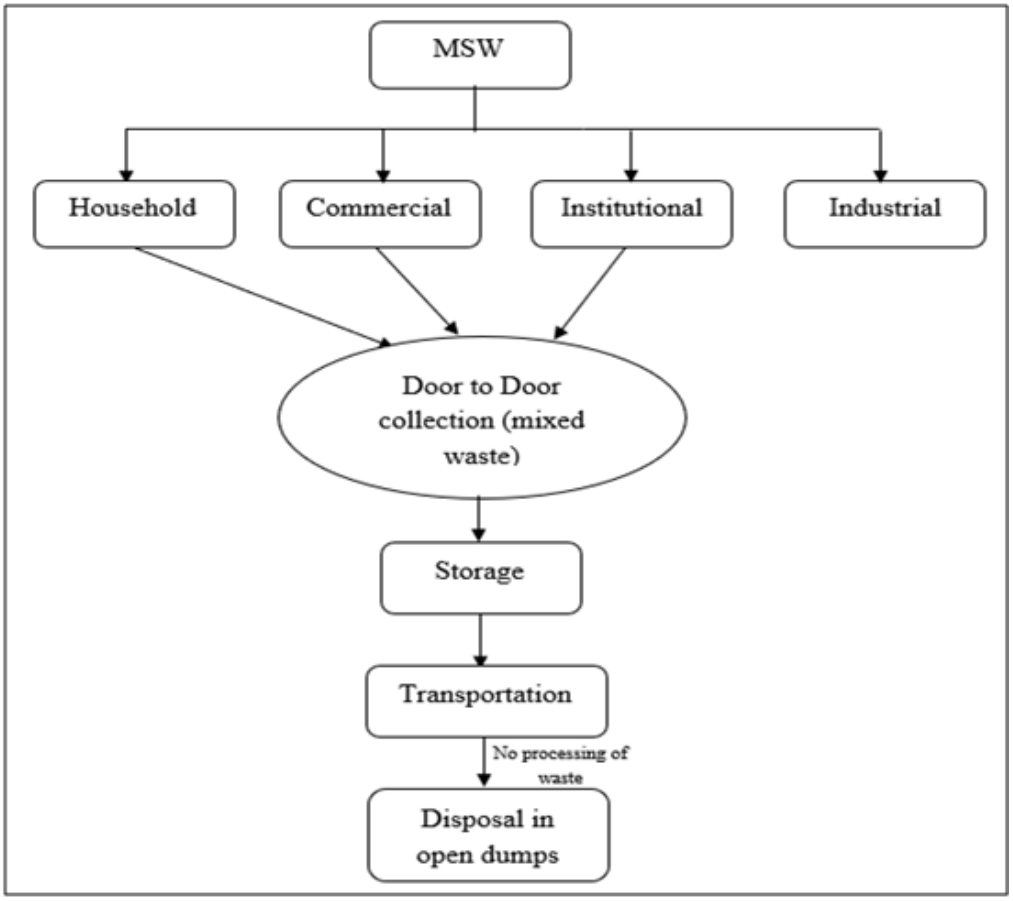

Figure 2.1: Waste management practices adopted in Una Himachal Pradesh.

2.1.2 Wasteaware Benchmark Indicators for Assessment

A system analysis of the MSW generated in Una town has been evaluated by the '*wasteaware*' techniques to evaluate its performance. The major issues like lack of suitable data and lack of

persistent data can be utilized for comparing the efficiencies of solid waste management system for different cities. In this context, '*wasteaware*' benchmark indicators were introduced which consists of both qualitative and quantitative indicators (Wilson et al, 2013; Wilson et al, 2015).

Quantitative indicators comprise of Public Health-collection, Environmental controlled disposal and Resource Management – reuse, reduce and recycling (as percentages) whereas the qualitative indicators are part of governance covering user and provider inclusivity; financial sustainability; and the national policy framework and local institutions (Wilson et al, 2013; Wilson et al, 2015).

2.1.3 Matrix Method of Evaluation of Existing Practices

A simple quantification method has been proposed using the matrix. The proposed grading system used in the wasteaware benchmarks is low (L), Low/Medium (L/M), Medium (M), Medium /High (M/H) and High (H), a certain weightage has been assigned to each of these. The assigned weights are (L=1, L/M=2, M=3, M/H=4, H=5).

2.2. Characterization of Municipal Solid Waste in Una, Himachal Pradesh

2.2.1 Introduction

The composition and quantity of MSW is influenced by a number of factors like living standards, seasons, food habits, source of generation and socio-economic conditions of the area. In this context, the present study focuses on the MSW characterization in Una town of Himachal Pradesh, a Tier-IV city. The characterization of waste involves the identification of different components of waste to be utilized for suitable treatment methods thus reducing the quantity of waste on land. The potential energy content from the MSW generated from the study location using experimental conditions was validated using empirical models.The characterization outcomes had been carried out for the generated MSW as no such outcomes exist and consequently has been compared with similar research carried out at different locations in Himachal Pradesh. Statistical analyses were carried out to determine the significances of the characterization results. The physical and chemical characterization of waste was done to observe the nature of waste and suitable treatment facilities were suggested to utilize the energy value by contributing to energy supplies and alleviating energy poverty.

2.2.2 Materials and Methods

Samples from all three cities were collected from vehicles unloading waste from commercial, institutional and household waste at the dumping sites. In accordance with the method, vehicles identified from the designated regions reaching the dumping sites were selected arbitrarily throughout each day of the 10 days sampling period to have an illustrative waste stream. A total of thirty samples (n = 10 for each site) were utilized for the study purposes. All the contents in the vehicles were emptied on a plastic sheet for preventing mixing of soil or any beneath water; 1000 kg of the waste sample unloaded from the vehicles was then reduced to 100 kg in second iteration. Segregation of the waste sample was done manually with the help of workers and rag pickers.

2.2.3 Physical Characterization

Determination of the physical composition of MSW is highly important as it helps in ascertaining the suitable technology for implementation of an effective waste management system. The samples collected were analyzed on wet weight basis (without any prior drying of waste samples for removal of moisture) and segregated into their components. The segregated component includes paper, polythene/plastic, clothes/textiles, organics/vegetables/horticulture, rubber/leather, glass, other mixed constituents like clothing, toy and sanitary items metals and inert.

2.2.4 Chemical Characterization

The proximate and ultimate analysis of the MSW was also performed to determine the fraction of crustal elements and ash content of the MSW as physical characterization provides information only regarding the main component fraction present in MSW. Various analyzed parameters include moisture content, volatile matter, ash content, fixed carbon and elemental analysis (C, H, N, S and O) and gross caloric value.

2.3 Effect of Degradation on Geotechnical Properties of Municipal Solid Waste

2.3.1 Introduction

The rate of degradation of waste is affected by many factors including composition, moisture content, pH, temperature and results in breaking down of MSW into finer particles. The properties of MSW thus gets affected due to decomposition of organic matter and increased moisture content thereby affecting the stability of landfill (Reddy et al., 2015, Machado et al., 2010, Feng et al.). However, the presence of water content and organic content in MSW

increased the degradation of waste and thus affects the long-term mechanical response due to disintegration of particles (**Reddy et al., 2015**). The degradation of waste results in reduction in volume and the settlement of waste occur about 30-50% of initial height of waste due to increased compression and overburden pressure (Sharma HD, Reddy 2004, Wraith 2002).

In this context, the properties of the waste were observed to get affected from fresh to decomposed state of MSW. The engineering properties of MSW affects the distribution of leachate and slope stability in landfill. The analysis of geotechnical characteristics provides a basis in designing a landfill and are however important in considering the stability during operation and after the closure of landfill. To avoid the catastrophic failure of landfill, evaluation of the effect of these changes on the geotechnical properties of MSW is important.

2.3.2 Materials and Methods

To observe the composition of waste, sampling of fresh waste was done for a week and representative sample of 100 kg was obtained. the samples were collected on a plastic sheet with help of rag picker and the components of waste like organic, paper, plastic/polythene, wood, metal and inert etc. were analyzed using segregation and were weighed for physical characterization. The moisture content was determined using dry gravimetric method and shredding of waste samples was done for the gradation. Sample collection points in the dump site for degraded samples have been shown in *Figure 2.3.1*.

Figure 2.3.1: Sampling points for degraded samples on dump site.

The waste samples of age between 0.5 year to 6 years were collected at varying depths from 0.5m to 6m to understand the effect of degradation on characteristics and strength properties of waste. The points of sampling were identified with help of MC Una personnel and workers at dump site. Depending upon the age of waste, representative samples covering MSW degradation period of 0.5 year, 1year, 2 years, 4 years and 6 years were collected and the collection points were marked as 1 to 5 respectively in Figure 2.2.

The degradation rate depends upon the presence of organic matter in fresh and degraded waste and was determined using following equation (Reddy 2015),

$$DOD = \left(1 - \frac{X_{fi}}{X_{fo}}\right)\frac{1}{(1 - X_{fi})} \times 100 \quad \ldots\ldots\ldots\

Shear strength testing of MSW is difficult because of the heterogeneous composition of landfill materials, difficulty in sampling, specimen preparation, testing, and range of particle size, and time-dependent properties, such as the age of the MSW and decomposition state, unit weight, etc. Published laboratory and field shear test data and back-analysis of field case histories are used herein to develop a better understanding of MSW shear strength and present recommendations for MSW strength to be used in static and seismic slope stability analyses of landfills (Stark et al., 2009, Zekkos et al., 2010b). With the increasing need for estimating the shear strength of MSW because of an emphasis on stability analyses after a number of landfill slope failures. This need is greatest because the height of proposed landfills is increasing. The increasing height of landfills is to increase disposal capacity and can involve a new facility or a vertical expansion of an existing facility.

In this context, the present study emphasis on analyzing the shear behavior of MSW using large scale direct shear test. The study estimated shear strength parameters of MSW and effect of degradation of waste on these parameters. The behavior of MSW with degradation and increased depth was observed.

2.4.2 Material and Method

The fresh and degraded waste samples of age varying from 0.5 to 6 years were collected with help of augur from the dump site. The samples were packed in plastic sheets and were brought to laboratory for moisture content determination as discussed earlier. Before placing the sample in the shear box, large metal and glass particles were removed, and plastic and paper were shredded into small pieces. The samples were then placed into the shear box layer by layer, and each layer was compacted with a hammer before the next one was added. The sample were tested using large scale direct shear apparatus of size (30 ×30 ×15 cm).

The contact surface between the two boxes was polished to reduce friction. Steel ball bearings were also installed below the lower shear box to further reduce friction. In addition, the apparatus was connected to a data acquisition unit which could display experimental conditions such as loading time, horizontal and vertical loads, and displacement. Samples from a given depth were compressed under four vertical loads (50, 100, 150 and 300 kPa), and each vertical load was maintained for at least 2 h to ensure that the settlement did not change further before shearing. The sample were sheared at displacement rate of 1mm/min under the increasing normal stress.

2.5 Effect of Open Dumping on Geotechnical Characteristics and Biodegradation Settlement of Soil

2.5.1 Introduction

Compression, consolidation and biodegradation of soil causes settlement of soil (**Bareither 2012, Pauzi et al., 2010**) thereby affecting the stability. Consequently, the biodegradation settlement of soil is a major factor depending upon the pH, temperature and moisture content (**Chakma and Mathur, Bareither 2012**). For reducing the impact of MSW on soil and environment, scientific disposal of waste should be done by constructing engineered landfill. However, the designing and operation of landfill depends upon the structural integrity, slope stability of structure (**Chen et al., 2010, Zekkos 2009).** Therefore, an assessment of settlement of soil is essential for maintaining the stability of landfill.

In this context, present study focuses on evaluating the effect of dumping on geotechnical characteristics of soil and comparison was done with the uncontaminated soil for estimating the level of contamination. Due to degradation of MSW, the effect on the characteristics, nature of soil and settlement have also been analyzed. In addition, the geochemical analysis of soil characteristics was also done to observe the elemental composition of soil.

2.5.2 Materials and Methods

The samples of soil were collected within the landfill site from different points and about 1 km outside the periphery of dump site for comparison. The depth of dump site varies from 5-8 meters which accepts the waste coming from households, institution, commercial areas etc. The contaminated and uncontaminated soil samples were collected with augur to obtain representative sample from the various points at depths of 0.5 m, 1.0 m and 1.5 m from the dump site. The sampling of soil was done during the months of March-April, prior to rainy season to avoid alteration in properties due to rain. The collected sample were packed in plastic bags and brought to laboratory for moisture content determination.

The collection points of samples of contaminated and uncontaminated sample have been presented in *Figure 2.5.1*.

Figure 2.5.1: Collection of soil samples from dump site.

2.5.3 Geochemical Analysis

The composition of soil minerals and morphology of soil were determined using Scanning Electron Microscopy (SEM) and Energy Disperse X-ray Spectroscopy (EDX) analysis.

2.5.3.1 Instrumentation Analysis

Scanning Electron Microscopy (SEM) and Energy Disperse X-raySpectroscopy (EDX or EDS)

SEM is morphological and topographical analysis and itprovides a beam of electron to deliver high resoluion image for analysing the surface of material. The SEM provides structure and physical features of material by the magnified images.

EDX or EDS is a chemical microanalyis technique which is used in combination with SEM. It characterize the elemenal composition by detecting the X-ray emitted from the sample during bombardment of electron beam.EDX provides the information regarding the elements and composition of material by heating the samples at 500-550°Cfor about half an hour.

2.5.4 Laboratory Analysis

The collected samples of soil were tested for determination of geotechnical parameters. The laboratory examination of these samples included the determination of specific gravity, dry density, particle size distribution, hydraulic conductivity, shear strength (c, ϕ values) and CBR of contaminated and uncontaminated soli samples. The testing of samples have been performed according to the guidelines of Indian Standards (IS: 2720:1983) for different geotechnical parameters as in Table 2.5.1.

Table 2.5.1: IS Standards for geotechnical Testing (IS: 2720:1983)

Sr. No.	Parameter	IS Code
1	Specific Gravity, G_s	IS:2720 (Part3/Sec 1)-1980 (Reaffirmed 2002)
2.	Particle Size Distribution	IS:2720 (Part 4)-1985
3.	Compaction	IS:2720 (Part 7)-1980
4.	Permeability	IS:2720 (Part 17)-1986
5.	Direct Shear Strength	IS:2720 (Part 13)-1986 (Reaffirmed 2011)
6.	California Bearing Ratio	IS:2720 (Part 16) -1987

2.5.5 Settlement Analysis

The settlement of soil can cause cracking and damage to the foundation of landfill. Due to dumping of waste, soil characteristics gets changed, causing the biodegradation settlement of soil (Park and Lee 2002). However, various models were proposed for analysing the biodegratadtion settlement of waste (Chen et al., 2010, Hettiarachchi et al., 2007, Yuen and Styles 2000, Chakma and Mathur 2007, 2013).

Different mathematical models have been presented in scientific literature to calculate biodegradation settlement of MSW (Park and Lee 2002, 2012, Babu et al., 2010, Bareither and Kwak 2015) but the model proposed by (Chakma and Mathur, 2007) helps in determining the biodegradation of the soil underlying the MSW. The details of this model have been discussed below:

The rate of change of mass depending upon moisture content (θ), temperature T, pH is predicted to follow equation. (2.1).

$$\frac{d(M_{sj})}{dt} = -k_j \xi(T, pH, \theta) M_{sj}, \ (j = 1,2,3,4) \tag{2.1}$$

where ξ is the function of pH ,moisture content θ) and Temperature (T) in fraction portrayed by Chakma and Mathur as shown by equation. (2.2).

$$\xi(T, pH, \theta) = \frac{T\theta \exp\left[-(pH-7)^2 \ln\frac{4}{3}\right]}{\left[1+\exp\left(\frac{T}{4}-18\right)\right]} \tag{2.2}$$

whereas, M_{sj} are the masses of different components of waste such as non- biodegradable (M_{s1}), slowly biodegradable (M_{s2}), moderately biodegradable (M_{s3}), and rapidly biodegradable (M_{s4}), with their respective rate constants k_1, k_2, k_3, k_4 .The decay rate of biodegradable waste (k) for slowly biodegradable, non-biodegradable, rapidly biodegradable and moderately biodegradable waste are categorized as 0.00001 day^{-1}, 0.00 day^{-1}, 0.001 day^{-1} and 0.0001 day^{-1}.

The total masses of N layer of soil become,

$$M_{s,N}(t) = \Sigma_{i=1}^{N} \Sigma_{j=1}^{j=4} (\%\, fi) M_{si,j} . \exp\left[- k_j \xi(T, pH, \theta) . t \right] \quad (2.3)$$

The volume of layers (V_s) at time (t) is evaluated by equation (2.4) proposed by researcher (Chakma and Mathur, 2007)

$$V_{s,N}(t) = \Sigma_{i=1}^{N} \frac{1}{\rho i} \Sigma_{j=1}^{j=4} (\%\, fi) M_{si,j} . \exp\left[- k_j \xi(T, pH, \theta) . t \right] \quad (2.4)$$

where, ρ = Density of soil substance

f = Percentage of soil beneath diverse classes

M_{si} = Masses of different components of soil

Now the strain (ε_b) due to biodegradation is estimated by using equation (Chakma and Mathur 2007, 2013),

$$\varepsilon_{b,i}(t) = \Sigma_{i=1}^{i=N} \frac{V_{i,N} - V_{S,N}(t)}{V_{i,N}} \quad (2.5)$$

$V_{i,N}$ denotes the initial volume of every layer.

Finally, the settlement at any time (t) due to biodegradation is then computed by equation (2.6), in which (H_i) is the initial thickness of each layer.

$$S_b(t) = \Sigma_{i=1}^{i=N} H_i \varepsilon_{b,i}(t) \quad (2.6)$$

2.5.6 Modelling Parameters

The soil comprised of layers of finite thickness and 5 m thickness of soil layer was assumed having 10 layers of 0.5m thickness each. The density of soil was evaluated and increased with depth. The MSW fractions were assumed to be mixed on the top layers of soil and having different phases of slowly degradable, moderately degradable, rapidly degradable and highly degradable content. The degradation constant (k) values 0.00001day^{-1},0.00 day^{-1}, 0.001day^{-1},

0.0001day^{-1} were taken for slowly degradable, non-degradable, rapidly degradable and moderately degradable waste respectively (Durmogous2005). In the literature temperature of 32°C to 42°C was considered as optimum temperature for biodegradation of MSW (Chakma and Mathur, 2007; Chen et al., 2010; Sharma and Reddy, 2004). Therefore, for biodegradation the favorable conditions at temperature of 32°C to 42°C and pH values for acidic and basic condition (2 to 14) are considered (Chakma and Mathur, 2007; Chakma and Mathur, 2013; Chen et al., 2010). The spatial variation in moisture content was observed with depth.

Density of soil:

$$\rho_z = \rho_m + (\rho_m - \rho_0).\frac{z}{z+12.4} \tag{2.7}$$

where, ρ_0 = initial value of density, kg/m^3, ρ_m = maximum value of density, kg/m^3

Moisture Content: Volumetric moisture content for depth (z) is evaluated as

$$\theta(z,0) = 0.20 + 0.01z \tag{2.8}$$

2.6 Analysis of Settlement of Municipal Solid Waste

2.6.1 Introduction

The settlement of municipal solid waste is associated with large reduction in volume of waste due to degradation of organic content of waste and initial compression. The biodegradation and settlement of MSW is affected by moisture content, temperature because of the presence of micro-organisms in waste (Wraith M. 2002). The settlement of municipal solid waste (MSW) is due to high compressibility under influence of biodegradation of organic content and overburden load. The settlement of MSW however occurs over a long period of time which can be up-to 30-50% of the initial height of the waste and contributes to different settlements rates (Ling et al., 1998, Park and Lee 2000). Settlement of landfill causes immediate compression that occurs due to external load applied or self-weight. Primary compression of waste is due to expulsion of water and gas from voids. The degradation process of MSW is time dependent process and thus properties of MSW changed due to degradation. The estimation of settlement due to biodegradation involves the determination using mathematical approach. Different methods have been proposed to predict settlement of MSW landfill by Edil et al., 1990, Babu et al., 2010, Ling et al., 1998, Zhao et al., 2001, Houssain et al., 2003, Hettiarachchi et al., 2007, Park and Lee 2007, Chen et al., 2010. Chakma and Mathur 2012). The anaerobic degradation of organic matters results in biodegradation settlement of MSW and methanogenesis of waste in landfill (Gource et al, 2010).

In this context, the present study focuses on determination of settlement due to degradation of

MSW using the mathematical model proposed by Chakma and Mathur (Chakma and Mathur 2007, 2013) and laboratory analysis of settlement over a period of time. The results from empirical methods are to be compared with laboratory analysis thus a laboratory set up is prepared for comparison of analysis.

2.6.2 Material and Methods

The 100 kg sample of fresh waste (2 weeks old) was collected from the landfill site for laboratory analysis. The composition of waste was analyzed and various categories of waste were obtained like paper, plastics, wood, combustible etc. The large particles (>40 mm) of waste were shredded and particle size distribution was established.

The waste sample was placed in reactor of size (600 x 600 x 400 mm) and load is applied on the sample with hydraulic cylinder connecting to perforated load plate (595 x 395 mm) connecting with waste sample. The waste sample was in 7-10 successive layers ensuring uniform density throughout (tamping layer uniformly to thickness of 5cm each). Placement of thermocouple to monitor the temperature, LVDT for displacement measurement and a gas measurement system (CO_2 and CH_4 sensors). Sealing of reactor to measure the gas generation. Monitoring and plotting of load, settlement, biogas generation, temperature data.

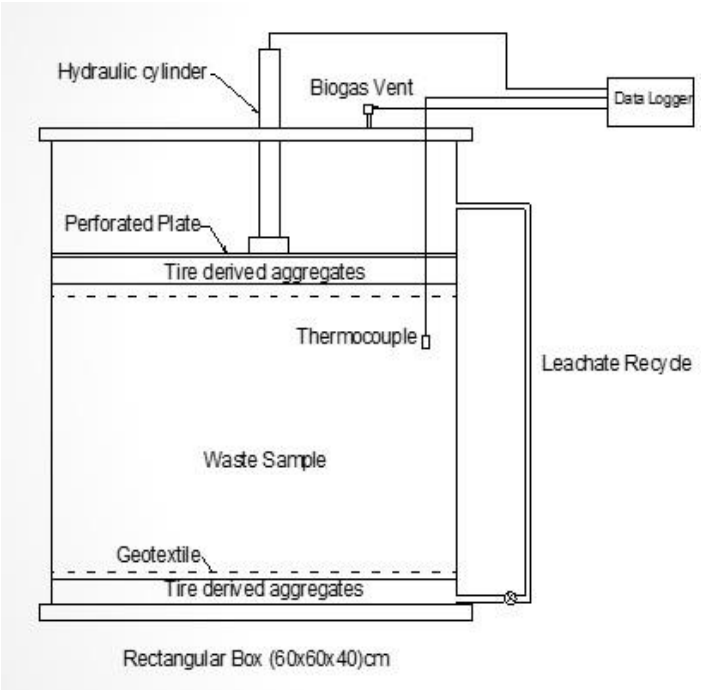

Figure 2.6.1: Schematic Diagram of laboratory set up.

3. RESULTS AND DISCUSSIONS

3.1 Current Status of MSW Management Practices in Una Town

The waste generation in the Una town is around 6 tons per day (TPD) with per person waste generation rate of 0.42 kg/day. About 5.5 TPD is collected out of total waste generated and finally disposed on an open land. The composition of MSW in study area showed presence of higher organic fraction as the area is agricultural and discarding of vegetables, rotten fruits and other biodegradable matters on dump site contributes in the increased organic matter. Also, the fraction of paper and polythene were found to be higher because of small scale industries, educational institutions and government/private sector offices. Despite of plastic ban in Himachal Pradesh, the generation of plastic is higher in the study region as it is in the border of neighboring state Punjab which does not follow the similar legislation.

3.1.1 Evaluation using Wasteaware benchmark indicators for sustainable waste management

The 'waste-aware' benchmark indicators were generated for Tricity and are presented in Table 3.1.1. The conventions used are for low score is 0-20% and coded as red, medium/low 21-40% coded as red amber, medium- 41-60% coded as amber, medium/high- 61-80%, green amber and high-81-100% coded as green. The obtained results for Una town were compared with Baddi, Solan, Mandi and Sundernagar as the nature of waste generated is similar with high fraction of organic matter (Sharma et al., 2018).

The *'wasteaware*' benchmarks parameters showed that study area has very good collection efficiencies as compared to other cities of state which showed 'low-medium' and 'medium' index on wasteaware benchmark indicators respectively. The disposal sites are unsanitary landfill in nature thus categorizing the environmental controlled waste treatment in study rea as low. Further, there is no lining provided at the landfill site to prevent the percolation of leachate in groundwater thereby contributing to environmental hazard.

3.1.2 Quantification of Indicators Using Matrix Method of Evaluation

The allocation of weights for the evaluated parameters from the benchmark indicators was done using matrix method. The results obtained have been presented in *Table 3.1.2* and *Table 3.1.3* presents overall score obtained using matrix method.

Table 3.1.1: Wasteaware Benchmark Indicator of Una, Himachal Pradesh.

Sr. No.	Category	Indicator	Una Town Results
Background Information of city			
B1	Country income level	World Bank income category	Lower-middle
		GNI per Capita	$1,140
B2	Population	Total Population of the city	18722
B3	Waste Generation	MSW Generation (tonnes/year)	2190
Key waste related data			
W1	Waste per capita	MSW per capita (kg per year)	153.3
W2	Waste Composition		4- Key fractions- as % of total waste generated
W2.1	Organic	Organic (food and Green wastes)	56%
W2.2	Paper	Paper and Card	12%
W2.3	Plastics	Plastics	10%
Physical Component			
1.1	Public health waste collection	Waste collection coverage	90% (M/H)
1C		Quality of waste collection service	89% (M)
2	Environmental control-waste treatment and disposal	Controlled treatment and disposal	< 10% (L)
2E		Degree of environmental protection in waste treatment and disposal	0% (L)
3	Resource management reduce, reuse and recycle	Recycling rate	0% (L)
3R		Quality of 3R's- reduce, reuse and recycle- provision	<10% (L)
Governance Factors			
4U	Inclusivity	User Inclusivity	51% (L/M)
4P		Provider Inclusivity	59% (L/M)
6N	Sound institution, proactive policies	Adequacy of national SWM framework	52% (L/M)
6L		Local institutional coherence	55% (L/M)

Table 3.1.2: Weightage assignment using matrix method

Sr. No.	Category	Indicator	Una Town Results
Quantitative Indicators (Public Health, Environmental Control, 3R)			
1.1	Public health waste collection	Waste collection coverage	90% (M/H) (4)
1C		Quality of waste collection service	89% (M) (3)
2.	Environmental control-waste treatment and disposal	Controlled treatment and disposal	< 10% (L) (1)
2E		Degree of environmental protection in waste treatment and disposal	0% (L) (1)
3	Resource management reduce, reuse and recycle	Recycling rate	0% (L) (1)
3R		Quality of 3R's- reduce, reuse and recycle- provision	<10% (L) (1)
Qualitative Indicator (Governance Factor)			
4U	Inclusivity	User Inclusivity	51% (L/M) (2)
4P		Provider Inclusivity	59%(L/M) (2)
6N	Sound institution, proactive policies	Adequacy of national SWM framework	52%(L/M) (2)
6L		Local institutional coherence	55%(L/M) (2)

The wasteaware indicator has been used to evaluate management system in Una town and consequently appropriate ratings were allocated to the qualitative and quantitative signs depending upon collected data. The benchmark indicators of study region had been compared with other regions of state (Sharma et al., 2018). The standard effectiveness of waste management system obtained from the Una region suggests overall weightage of 38% and for Baddi (32%), Solan (32%), Mandi (36%) and Sundernagar (32%). Analysis discovered that the quantitative parameter of "wasteaware" benchmark has weightage 36% for Una and 30% for Baddi, Solan, Mandi and Sundernagar. The qualitative parameters have weightage 40% for Una and 35% for Baddi and Solan and 45% for Mandi and Sundernagar. The benchmark indicator of study region was found to be similar with other regions of state except collection efficiency.

The benchmark indicator evaluated in Table 3.12 showed that the collection efficiency and collection services are good in Una categorized as M/H whereas for other study locations in the state classified as L/M (Sharma et al., 2019), but the environmental management and management of resource is very poor for the Una town and categorized in low index (L) similar to those observed for other study locations within the state (Sharma et al., 2019). The provision

for the treatment, disposal and recycling of the waste is negligible in the Una town. The results obtained in the *Table 3.1.2* and *Table 3.1.3* using the benchmark indicator and matrix method has been compared with other cities of state having same characteristics of MSW. Thus, the outcomes from the matrix analysis confirmed that management of MSW for study area and other regions of Himachal Pradesh is indexed as low.

Table 3.1.3: Overall Score obtained using matrix method.

Sr. No.	Category	Indicator	Una Town Results
Quantitative Indicators (Public Health, Environmental Control, 3R)			
1.1	Public health waste collection	Waste collection coverage	4
1C		Quality of waste collection service	3
2.	Environmental control-waste treatment and disposal	Controlled treatment and disposal	1
2E		Degree of environmental protection in waste treatment and disposal	1
3	Resource management reduce, reuse and recycle	Recycling rate	1
3R		Quality of 3R's- reduce, reuse and recycle- provision	1
Total Score (Quantitative Indicator)			11
Maximum Score			30
Weightage (%)			**36**
Qualitative Indicator (Governance Factor)			
4U	Inclusivity	User Inclusivity	2
4P		Provider Inclusivity	2
6N	Sound institution, proactive policies	Adequacy of national SWM framework	2
6L		Local institutional coherence	2
Total Score (Qualitative Indicator)			8
Maximum Score			20
Weightage (%)			**40**
Total Score (Overall)			11+8=19
Maximum Score			30+20+50
Overall Weightage (%)			**38**

3.2 Characterization of MSW

3.2.1 Physical and Chemical Characterization of MSW

The results of physical and chemical characterization of MSW from Una are presented in Table 3.2.1 and Table 3.2.2.

Table 3.2.1: Physical characterization of MSW from Una town.

Sr. No.	Components	Summer	Monsoon	Winter	Average
1	Organic matter	58.6±2.23	56.3±1.28	53.4±3.44	56.1±1.08
2	Paper	10.6±0.35	13.9±1.85	12.12±1.26	12.2±0.76
3	Polythene/Plastic	10.3±1.77	10.1±0.80	10.61±0.69	10.3±0.59
4	Glass	0.9±0.21	1.1±0.21	1.09±0.15	1.0±0.03
5	Metal	1.4±0.94	0.9±0.18	1.13±0.54	1.2±0.38
6	Inert	10.0±2.67	10.0±1.30	11.2±2.36	10.5±0.72
7	Others	8.2±1.44	7.7±1.07	10.45±1.23	8.7±0.19

Note: All component values are in percentage (%).

Number in the parentheses is standard deviation.

Other includes leaves, wooden matter, thermo-cole, etc.

Table 3.2.2: Chemical characterization of MSW from Una town.

Parameters	Unit	Seasons			Average
		Summer	Monsoon	Winter	
Proximate Analysis					
Moisture Content	% by wet weight	40.2±3.59	61.3±5.19	48.22±5.15	49.9±4.64
Ash content	% by dry weight	27.34±5.68	20.24±1.37	27.02±3.52	24.87±3.52
Volatile Matter	% by dry weight	29.57±5.50	16.43±3.25	20.60±1.18	22.2±3.31
Fixed carbon	% by dry weight	2.89±0.73	2.03±1.02	4.16±0.64	3.03±0.80
Calorific value	(kcal/kg)	2543±176.55	1953±104.73	2292±102.16	2263±127.82
Ultimate Analysis					
Carbon	% by dry weight	28.59±1.24	37.29± 2.20	31.51±1.29	32.46±1.58
Hydrogen	% by dry weight	4.90±0.10	2.66±0.55	3.97±0.29	3.84±0.31
Nitrogen	% by dry weight	1.36±0.11	1.56±0.51	1.39±0.13	1.44±0.25
Sulphur	% by dry weight	0.08±0.001	0.10±0.003	0.14±0.001	0.11±0.002
Oxygen	% by dry weight	16.55±4.02	11.62±2.11	13.83±1.03	13.99±2.39
Potassium	% by dry weight	0.67±0.08	0.63±0.08	0.52±0.04	0.62±0.07
Phosphorous	% by dry weight	0.45±0.06	0.37±0.05	0.39±0.06	0.40±0.06
Mineral Content	% by dry weight	47.40	45.77	48.28	47.15
C/N ratio	-	21.02	23.90	22.7	22.72

The results also showed the presence of paper and plastic in higher fraction in the study area. The fraction of paper is higher about 12.2% owing to the existence of many educational institutes (schools, colleges), govt. and private sector offices etc. The inorganic fraction of waste includes plastic/polythene, metal, glass and other miscellaneous materials. The amount of total inorganic fraction in waste was observed to be 31.7% for study area. Plastic/polythene is major

component of inorganic waste which was found in higher proportion about 10.3% despite of the fact that Government of Himachal Pradesh has banned the use of plastic bags, packets and pouches since 2003. But being in the border region with Punjab where no such legislation is present, the plastic is disposed due to influx of tourists. The consumption, carrying of goods and services, transient population from the adjoining and nearby cities or state, contributes in generation of waste. The plastic waste generation in other regions like Mohali (6.6%), Chandigarh 97%) Jalandhar (9%), Bhopal (10%) was found to be very less (Rana et al., 2017, Katiyar 2013, Sethi et al., 2013). Metal and glass were in very small fraction (about 2%) in waste due to lack of large-scale industries producing such materials.

The informal recycling by rag pickers was observed during the sampling, which reduced the fraction of such materials from waste. However, the inert fraction of waste was in higher proportion about 10.5% in waste due to waste coming from street sweeping, construction and demolition operations. The presence of inert fraction in waste reduces the calorific value of waste and thereby increasing the density of waste (Sethi et al., 2013, Gomez et al., 2009). Miscellaneous materials in category *others* (8.7%) like wood, thermocole, textiles etc. were also found in waste generated from commercial, institutional sectors in study area.

The results obtained from the proximate analysis of MSW showed that the average moisture content of waste was about 50% which varied between 40-61% for the three seasons. Further, the ash content of the MSW were almost similar for both summer (27.34%) and winter season (27.02%) because of the increased burning of waste on dump site during summer season and use of wood, coal for heating purposes during winter which increased the amount of ash content in waste. The volatile fraction for three seasons varied in range of 16-30% having the highest percentage in summer (29.57%). The higher percentage of volatile matter (average 22.2%) in waste due to high fraction of biodegradable matter present in MSW. These results were observed to be in same range with other cities like Baddi, Solan, Mandi and Sundernagar wherein the values lie in range of 23-28% and for tricity of Chandigarh 17-28%.

Consequently, the average calorific value of waste was observed to be 2263 kcal/kg with highest value reported in summer season (2543 kcal/kg). Similar studies carried out in cities of state and nearby region showed that the calorific value of waste in Himachal Pradesh varied between 2327-2667 kcal/kg and for Chandigarh 2508 kcal/kg, Mohali 2208 kcal/kg (Sharma et al., 2019, Rana et al., 2017b). Reported studies for metropolitan cities like Mumbai, Delhi, Chandigarh showed high calorific value of waste as 7477 kcal/kg, 4498 kcal/kg, 1929-2508 kcal/kg

respectively which the waste suitable for energy generation (Lohri e al., 2014, Komilis 2012, Sharholy et al., 2008, Rana et al., 2017b).

3.2.2 Heavy Metal Characterization

The presence of heavy metals in MSW have been presented in *Table 3.2.3*. The results showed that heavy metals present in MSW were within the permissible limits prescribed by US Environmental Protection agency (US EPA 2000) and MSW Rules (2016).

Table 3.2.3: Heavy metal characterization of MSW.

Parameters (mg/kg)	Seasons			Average	Permissible Limit (Mandal et al., 2014)
	Summer	Winter	Monsoon		
Pb	0.01	0.01	0.01	0.01	100.00
Cu	156.04±7.88	127.37±9.18	139.97±1.74	141.13±0.58	300.00
Cd	0.001	0.001	0.001	0.001	5.00
Fe	882.13±65.49	715.47±41.09	726.47±75.32	774.69±25.11	-
Ni	0.01	0.01	0.01	0.01	50.00
Cr	22±1.41	17.16±4.15	19.02±2.85	19.39±0.95	50.00
Zn	23.86±5.1	22.65±5.27	21.50±7.44	22.67±2.48	1000
Mn	12.13±1.82	9.35±4.73	11.63±1.33	11.04±0.44	-

Note: Number in the parentheses is standard deviation.
All values are in percentages (%).

The presence of copper (Cu), chromium (Cr), zinc (Zn) found in MSW could be attributed to the water-cooling industries, leather and paint industries in the study area. The presence of heavy metals like lead (Pb), cadmium (Cd), nickel (Ni) in MSW was in very small fraction but require consideration because small concentration of these metals could be harmful. The results obtained from the analysis are used for selecting the different treatment and processing facility for MSW and utilizing the energy value of waste.

3.3 Geotechnical Properties of MSW

3.3.1 Physical characterization of MSW

Initially, the physical characterization of MSW samples was done according to US EPA (2010) during the sample collection. Table 3.3.1 represents the physical characterization of fresh and old MSW in the site. It was observed that the biodegradable fraction comprised of 68.3% and the non-biodegradable fraction was observed to be 31.7% of total waste. As the age of waste increases, the biodegradable matters present in waste tends to degrade. The fraction of organic

matter in waste decreases to about 12.2 % to 3.3 % for waste age from 6 months to 6 years. Thus, inert fraction in waste increases to 70.3 % to 80.53 % for old waste which is much less for fresh waste.

Table 3.3.1: Characterization of fresh and degraded MSW in Una, Himachal Pradesh.

Sr. No.	Components	Composition (%)					
		Fresh Waste	Degraded Waste				
			3-6 months	1-1.5 years	2-3 years	3.5-4.5 years	5-6 years
1	Organic matter	56.1	12.2	5.53	6.58	4.3	3.3
2	Paper	12.2	2.53	1.35	1.89	1.03	0.76
3	Polythene/Plastic	10.3	4.34	2.48	2.27	2.31	1.12
4	Glass	1.0	0.6	1.2	1.5	0.6	0.2
5	Metal	1.2	0.93	1.04	1.86	0.51	0.16
6	Inert	10.5	70.3	75.1	74.3	78.46	80.53
7	Others	8.7	9.1	13.3	11.6	12.79	13.93
	Total	**100**	**100**	**100**	**100**	**100**	**100**

3.3.2 Geotechnical Characteristics

The specific gravity of fresh waste was 1.83-1.92 and old waste was found to be in the range of 1.85-2.28 as given in Table 3.3.2.

It was observed from Table 3.3.2 that with a decrease in particle size, an increase in compaction, degradation of waste, specific gravity of sample increases. The organic content of waste samples decreased due to the decomposition of organic matter with time. The increase in age of waste sample causes an increase in the degree of decomposition.

Table 3.3.2: Properties of waste samples (Fresh and Degraded)

Sample	Age (years)	Moisture Content (%)	Specific Gravity (G_s)	Organic Content (%)	Comparison with literature	
Fresh	0	49.5	1.83±0.05	74.1	G_s= 0.85 Moisture content = 44% O.C = 76-84%	Reddy et al., 2009c
					G_s= 1.89-1.95 Moisture content = 35%	Feng et al., 2016
					G_s= 1.34 Moisture content = 46%	Breitmeyer 2011

Landfilled (old) Sample	3-6 months	44.3	1.85±1.97	38.1	**0.3 year**, G_s-1.83-2.27, m/c- 42.5-47.9 **2 years,** G_s – 1.88-1.93, m/c- 58.5-68.9% **2-2.5 year**, G_s -1.95, m/c- 43.9, O.C- 33.1% **3-4 year**, G_s -2.00, m/c- 35.8, O.C.- 21.1% **4.5-6 year**, G_s -2.40, m/c- 20.1, O.C.- 15.9% G_s - 1.51(S), 1.88(M), 2.14 (D)	Feng et al., 2016 Ramaiah et al. 2017 Wu et al., 2012
	1-1.5 year	51.6	1.93±2.04	26.1		
	2-3 years	48.9	1.91±2.24	29.8		
	3.5-4.5 years	46.4	2.15±2.28	33.2		
	5-6 years	39.8	2.14±2.23	20.75		

The results obtained showed that the waste from the study area having variation in specific gravity for a fresh and degraded waste of about ≈1.2-3.2% and ≈0.44-1.1%, 5-8% respectively with the literature. For moisture content, variation results from ≈12.5-60% for fresh and 6-33% for degraded waste. The unit weight of MSW varies from 3-8% for fresh and 1-17% for degraded waste. Thus, the results showed that variation in waste characteristics was due to a change in the composition of MSW for different cities and countries. Hydraulic conductivity of MSW depends upon degradation, varies 9% for fresh and 13% for degraded MSW. The variation in φ, c of the waste was approximate 15-20%, 5-25% for fresh waste and 17-37%, 29-35% for degraded waste respectively. The variation in cohesion and angle of internal friction is more due to reason that the fresh waste of the current study area has fewer fibers content which causes the lesser c, φ and the degradation of MSW is lower than compared literature thus having a large variation in properties. the observed result of geotechnical testing of MSW are presented in Table 3.3.4.

Table 3.3.4: The test results for fresh and degraded MSW

Sr. No.	Parameters	Fresh	Degraded
1	Specific Gravity (G_s)	1.83±0.05	1.85-2.28
2	Moisture Content (%)	49.5±1.05	39.8-51.6
3	Organic Content (%)	74.1±2.17	20.75-38.1
4	Unit Weight (kN/m^3)	6.97±0.85	7.05-10.4
5	Dry Density (kN/m^2)	4.28	4.47-6.25
6	OMC (%)	78.1	80.2-85.4

7	Hydraulic conductivity (m/sec)	1.3×10^{-4}	1.34×10^{-5}
8	Cohesion, c (kPa)	36.3	39.2- 45.02
9	Angle of internal friction, φ	14°	13°- 22°
10	Compression index	0.19-0.29	0.12-0.17

3.4 Shear stress behavior of Municipal Solid waste

The results obtained from the large direct shear test of MSW observed that the shear strength of MSW increases with normal stress. It should be noted that the shear strength increased significantly under the same stress, but the difference with increasing depth is very small. Therefore, the shear strength changed substantially within the shallow layer but more slowly with deeper layer down. Depending upon the observed results of MSW testing the best fit failure envelope was drawn for the MSW as shown in Figure 3.4.1.

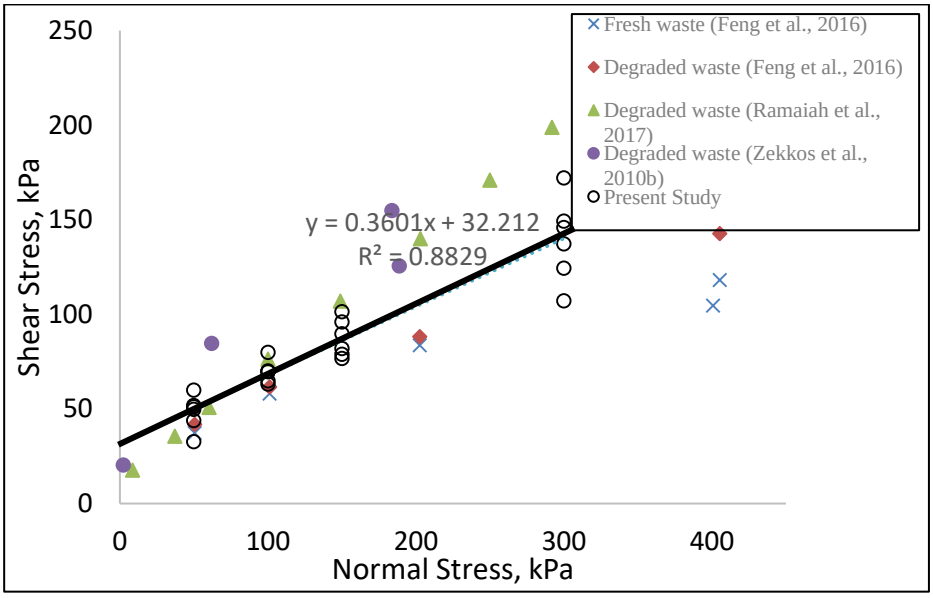

Figure 3.4.1: Best fit shear strength parameter for MSW and comparison with literature.

3.5 Effect of Open Dumping on Geotechnical Characteristics and Biodegradation Settlement of Soil.

3.5.1 Geochemical Analysis of soil

The result of analysis by SEM and EDX showed that the geometric arrangement of particles and structure of soil sample, shape of particle and elemental composition of the soil for contaminated soil samples and natural soil. The EDX analyses of the contaminated sample revealed the composition of elements, series and distribution of the atomic weight in soil. The eight elements detected in contaminated soil were oxygen, sodium, magnesium, aluminium,

silica, potassium, calcium, iron. The percentage atom of oxygen is higher in contaminated soil followed by silica and alumina. The presence of five elements oxygen, aluminium, silica, potassium and iron, having higher atomic and weight concentration of oxygen and silica in uncontaminated soil. The uncontaminated sample has appreciably high composition of silica content. The concentration of silica in soil showed the presence of quartz mineral in soil. The SEM micrographs showed that soil fraction consists of roughly spherical and largely irregular particles for samples.

3.5.2 Geotechnical Analysis of Soil

Particle Size Distribution

Sieve examination for particle size distribution of contaminated and uncontaminated soil samples are carried out as per Indian Standards. The particle size distribution curve for contaminated soil and uncontaminated soil depict that sample is mainly composed of sand. However, curve showed that sample collected at 0.5m depth consists of degraded waste fraction which results in presence of finer particle. The particle size distribution for contaminated soil and uncontaminated samples are shown in Fig. 3.5.1 (a,b).

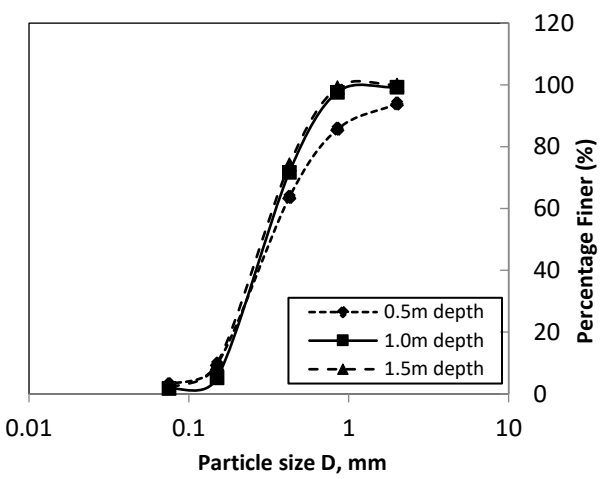

Fig. 3.5.1(a) Particle Size Distributions for contaminated soil.

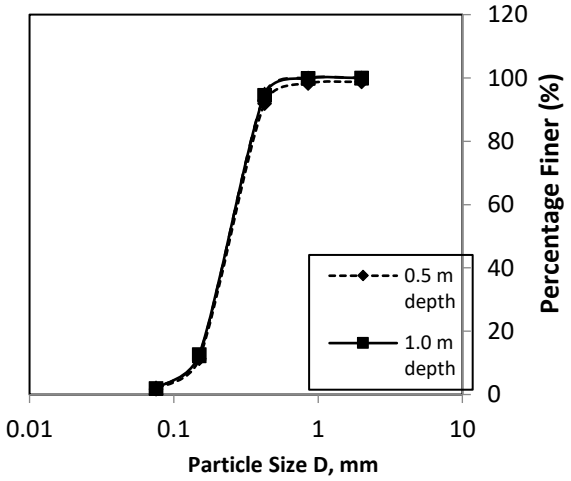

Fig. 3.5.1(b) Particle Size Distributions for un-contaminated soil.

Specific Gravity

The analysis was performed by specific gravity bottle (500 ml flasks) (IS: 2720, Part 3/Sec 1). It could be noted that uncontaminated soil has highest specific gravity as compared to contaminated soil. The organic content present in soil varies with depth from 1.25% to 0.385%. This variation in organic content is because of MSW fraction present in top layer of soil.

Moreover, it can be seen that soil tendency to convert into organic soil is found to increase with increase in leachate migration as lowest specific gravity is observed for soil at 0.5m depth for contaminated soil.

Compaction Characteristics

The compaction behavior of samples is tested as IS code (IS: 2720, Part-7, 1980). As per the particle size distribution curve; it is observed that all soil samples are primarily sandy soil.

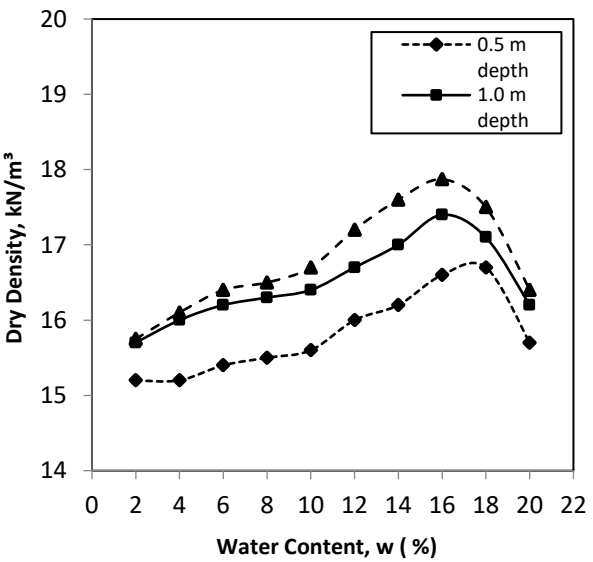

Fig. 3.5.2(a) Compaction Curve of contaminated Soil from Standard Proctor Test.

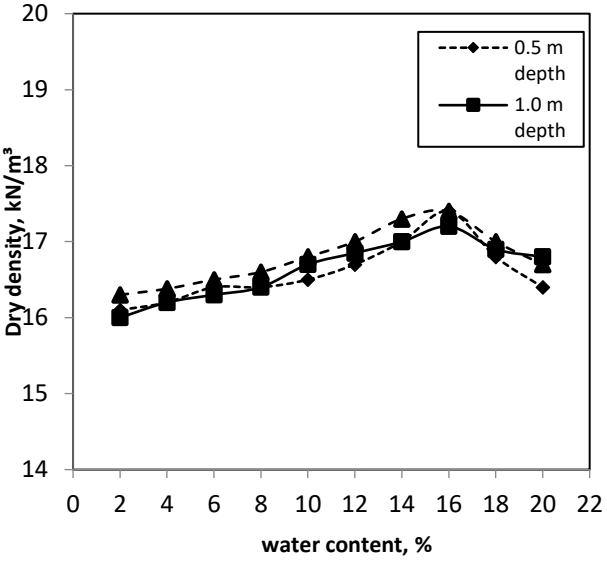

Fig. 3.5.2(b) Compaction Curve of uncontaminated soil from Standard Proctor Test.

From the curves it was observed that variation in the MDD of soil is because of contamination of soil in the dump site is due to leachate. The compaction curve shows that sample at 0.5m depth has lower MDD value than at depth 1.5m but there is no much variation in values below 1m because impact of MSW dumping is decreased. The highest dry density of contaminated soil minimized from 17.18 kN/m^2 to 16.5 kN/m^2 and optimum moisture content of soil increased from 15.8% to 17.5% with increasing effect of MSW on the soil. The MDD of uncontaminated soil is more than contaminated soil.

Permeability

Permeability characteristic of soil samples is determined using constant head method for cohesion less soil as per IS Standard (IS: 2720- Part 17, 1986*)*. It is observed that permeability of contaminated soil is less as compared to uncontaminated soil. The reason for variation in k can be due to accumulation of heavy metals which migrates along with leachate through the soil. The permeability of soil at upper layer (0.5m) is less than soil at 1m and 1.5m depth.

Permeability of dump soil varies with depth from 2.57×10^{-5} to 2.32×10^{-4} cm/sec for dump soil and $5.8 \times 10^{-4}\ to\ 6.7 \times 10^{-4}$ cm/sec for uncontaminated soil. The heavy metal gets deposited in soil matrix thereby inducing bond between soil particle and leachate film which reduces the size of pores. This deposition of heavy metals limits the water flow via the soil and hence decreasing soil permeability.

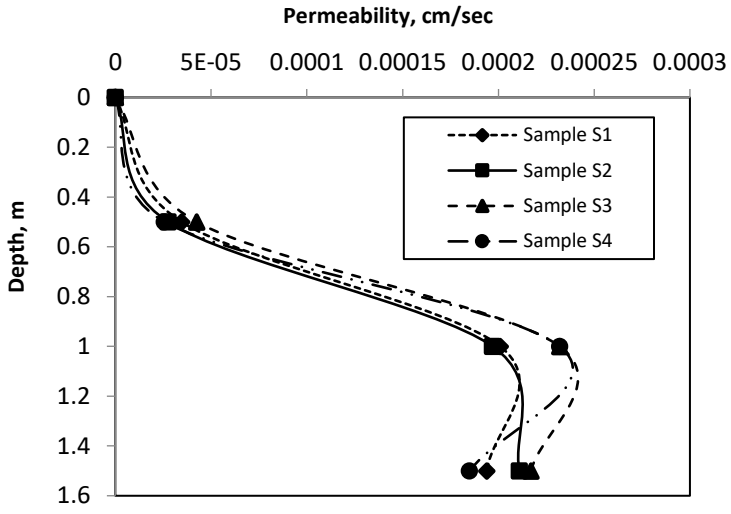

Fig. 3.5.3: Variation of permeability of contaminated soils with depth.

Shear Strength

The shear strength constraints of soil are portrayed by means of direct shear analysis as given in (IS: 2720 (Part 13). The angle of internal friction for sample collected within dump site ranges from 18.64° to 20.55° for 0.5m depth with increased cohesion and increases from 21.05° to 25.41° for 1.0 to 1.5 m depths with lower cohesion values. The increase in ϕ can be due to soil degradation by microorganisms which makes contaminated soil orient into a denser packing. Since particle degradation of contaminated soil can be expected, it could further lead to production of more angular particles and consequently a higher ϕ.

California Bearing Ratio Test

The soil specimens from the dump site were analyzed for CBR using IS Standard 2720 (IS:2720, Part-16 (1986). The variation of CBR values of samples under soaked and un-soaked conditions. The plot of load-penetration is obtained and CBR values for penetration of 2.5mm and 5mm are determined. The CBR value of dump soil varies in range of 4.63%-5.62% for un-soaked condition and 1.52-2.07% for soaked state. The CBR value for natural soil varies from 5.45-5.81% for un-soaked and 1.77-2.03% for soaked conditions respectively. The CBR value of dump soil as compared with the natural soil decreased by 12% -17% and 20-25% for un-

soaked and soaked conditions respectively.

3.5.3 Biodegradation Settlement Analysis of soil

Variation of settlement with changing pH of soil (temperature and moisture content constant)

Based upon the actual parameters and assumed values of pH, moisture content and temperature, settlement of soil is evaluated. The settlement of soil with time for actual moisture content, temperature with varying pH values. The result showed that the increase in settlement of soil for acidic (pH-2) and alkaline (pH-12) nature are almost same and increased at a very slow rate. However, the variation in pH values (actual pH of soil samples, 4, 9) showed the increase in settlement having significant increase in successive years. It can be observed from the results that the rate of degradation of soil is more owing to growth of micro-organisms present in soil which tend to grow in moderate pH conditions.

Variation of settlement with changing moisture content of soil (constant pH, temperature)

Settlement with changing moisture content observes increase in settlement of soil. The actual parameters for temperature and pH were used for estimating temporal and spatial variation of moisture content. It was observed from the results that settlement increases with increase in moisture content. The variation of settlement with moisture content. It can be seen that difference in settlement is less for initial 1-5 years and then increases with time.

Variation of settlement with change in temperature of soil (constant pH, moisture content)

The variation in settlement with observed and predicted temperature during the different time. It was observed from the graph that the variation in temperature leads to biodegradation of organic matter. With the increase in temperature, settlement of layer increases significantly. Settlement of soil starts significantly after 5^{th} year and continuous increase was observed for next successive years. The increase in temperature promotes the growth of microorganisms results in decomposing the material. The obtained result depicts that the settlement at actual temperature condition during sampling period is significant and increases with time.

3.6 Settlement Analysis of Municipal Solid Waste

Settlement of landfill causes immediate compression that occurs due to external load applied or self-weight. Primary compression of waste is due to expulsion of water and gas from voids. It

occurs because of overlying weight at particular point. However, the settlement of waste is due to biodegradation of organic waste and continues for many years. The biodegradation of solid waste causes the secondary settlement in landfill affecting the performance of landfill. The degradation process of MSW is time dependent process and thus properties of MSW changed due to degradation. The observed results from the settlement analysis observed the total settlement of 46.8% after application of load. Initially the rate of settlement of waste is higher and then primary settlement of waste was observed after 48 hours of application of load. Figures 3.6.1 showed the total settlement and secondary settlement of MSW under the constant loading of 50 kPa.

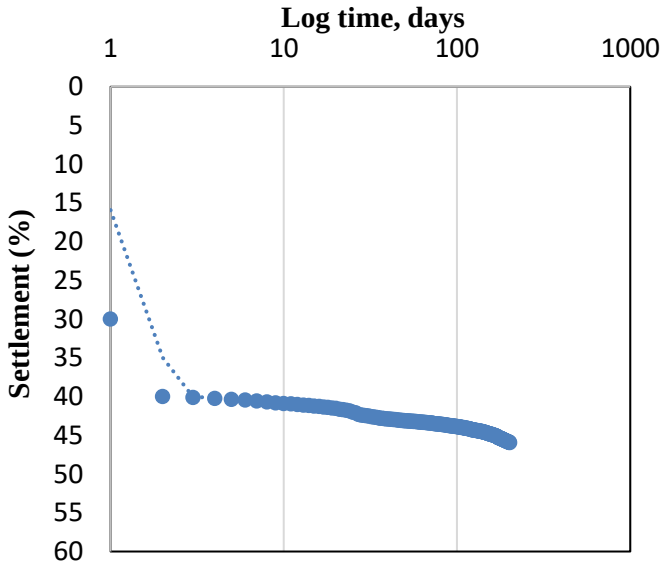

Figure 3.6.1. settlement of raw MSW at 50 kPa.

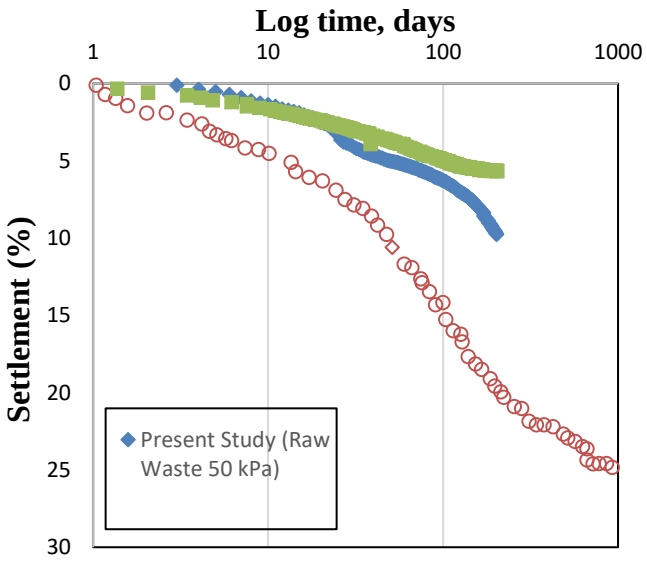

Figure 3.6.2. Secondary settlement of MSW at 50 kPa.

4. CONCLUSIONS

- The current practices for waste management in study area indicates that the collection efficiency of the waste is about 80-90% which is quite better than the other cities of the state but lack of segregation, transportation, storage and treatment facilities has led to poor and ineffective management system. The benchmark analysis and matrix method also evaluated the efficiency of the waste management system in the area which showed poor collection and management system in the study area. The treatment and 4R's facility in the area is having poor performance in study area. The waste is dumped in the open sites, thereby contributing to environmental pollution.
- The investigation of present study will be useful in adopting better management strategies and waste treatment and disposal options. Based on the MSW characterization it is

suggested that the calorific value of the waste can be utilized for the energy recovery and thus, estimation of energy content of MSW helps in achieving the optimal system performance. Different techniques for energy generation have been discussed including energy generation separately from organic and inorganic fractions and combined treatment systems.

- The degradation of waste changes the properties of waste which are important for designing the various components of landfills. The moisture content present in waste is high due to organic content in fresh waste which accelerate the growth of micro-organism in waste. The unit weight of waste sample increased with increased depth and age of sample. The hydraulic conductivity of landfilled waste is less than fresh waste attributed to increased finer particles in degraded waste. Also, the shear strength of waste samples increased with application of stress and the compression index of waste reduces with degradation. These evaluated parameters showed significant variation in properties with degradation and age of MSW. The degradation of waste results in the differential settlements and thus it is necessary to assess the stability of landfill. The accumulation of leachate in waste results in build-up of excess pore water pressure resulting in the seepage failure. Thus, the investigation of geotechnical properties is important to assess the changes with degradation and to avoid catastrophic failure. Depending upon the geotechnical analysis, the effect of MSW on soil is determined and its remedial measures for minimizing the harmful effect along with the recreation of soil needs to be done.

- The shear strength of the MSW obtained in this study was lower than the reported values in other countries, which was caused by the less fibrous materials in the specimens in this study. It was observed that the shear strength parameters of MSW increased with increase in degradation of MSW. The shear strength increased with normal stress, displacement rate and unit weight of MSW. However, the shear strength of waste changed substantially within the shallow layer but more slowly with deeper layer down.

- The geotechnical characteristics of soil were observed to be affected due to open dumping having higher effect on the upper layer of soil. The value of specific gravity in lower layers is similar to uncontaminated soil which showed that level of contamination in lower layers is lesser which has not much affected the properties of soil. This reduction in MDD is due to degradation of organic substance available in waste. Consequently, decrease in void ratio is attained and hence smaller permeability of contaminated soil.

The electrically neutral sand particle gets charged due to deposition of heavy metals thereby increasing bonding between soil particles and inducing apparent cohesion. Hence, it could be concluded that shear strength of contaminated soil is higher than uncontaminated soil. The higher values of cohesion and smaller angle of internal friction of dumpsite soils reveal reduced shear strength when distinguished with natural soil.

- The overburden load in landfill occurs due to additional overlying waste layer and thus increasing the stress at various depths. The degradation of organic matter of MSW occurs due to micro-organisms present and moisture content which influences the physical stability of structure. The mechanical creep and bio- compression occurs under constant vertical stress and are time dependent processes. The mathematical model used to predict the settlement showed the effect of moisture content, pH and temperature on degradation. Thus, the mathematical modelling of predicting the settlement of landfill showed that initially the rate of settlement of MSW was high due to high degradation rate of organic contents.

Scope of Future Work

- Assessment of environmental impact of open dumping in Himachal Pradesh.
- The sensitivity analysis of degradation constant and gas generation needs to be conducted for estimating the settlement.
- Further investigation needs to be done for analysing the characteristic of leachate produced, identifying the presence of potentially harmful organic substances which may affect the degradability of MSW.
- Development of numerical model for understanding the landfill processes of waste degradation, leachate quality and gas production for predicting the long-term settlement.

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